THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

NOVEMBER, 1954

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Precision Investment Casting of Nickel-containing Materials

'Investment Castings. Repetition Production of High-Precision Work at the Napier Foundry.'
Automobile Engineer, 1954, vol. 44, Sept., pp. 367–73.

A detailed and well illustrated step-by-step account is given of methods employed in the foundry of D. Napier & Son, Ltd., Park Royal, where precision investment casting is used for production of aircraft gas-turbine blades and of a large number of component parts of such diverse equipment as sewing machines, dairy apparatus, fuel pumps, hydraulic gear, surgical instruments, automobiles, and metal-working tools.

A table shows the properties typical of precision-cast test pieces produced in the Napier foundry. The steels and alloys in which such castings are made include materials of low and high nickel content.

Nickel-containing Materials used for Weights

NAT. PHYSICAL LABORATORY: 'Balances, Weights and Precise Laboratory Weighing.'
Notes on Applied Science No. 7; published by Dept. of Scientific and Industrial Research, 1954; 46 pp. Obtainable from Her Majesty's Stationery Office, London; price 2/-.

This publication is one of a series published by the National Physical Laboratory with the object of providing, for industrialists and technicians, information on various scientific and technical subjects which is not readily available elsewhere. The scope of the material contained is indicated below:—

Part I. Knife-Edge Balances: Chief features, functioning and adjustment of the simple equal-arm balance; some particular types of balance; the balance in service; balance tests; representative list of balances.

Part II. Weights: Materials used; construction; adjustment; weights boxes; testing and verification; stability.

Appendices:

I. Simple theory of the equilibrium of an equal-arm knife-edge balance.
II. The motion of the damped bean.
III. The effect of air-buoyancy on a single-pan balance.
IV. References to the literature.

In the section relating to materials for weights the following metals and alloys are recommended:—

For small weights: up to and including 0·5 gramme (6 grains):—

platinum or platinum-iridium,
gold alloy,
nickel-chromium alloy (80–20 per cent.),
25–20 per cent. chromium-nickel steel,
tantalum,
aluminium: for weights not larger than 0·1 gramme (1 grain).

It is specifically emphasized that nickel should not be used, due to its magnetic properties.

For larger weights: greater than 0·5 gramme (6 grains):—

nickel-chromium alloy (80–20 per cent.),
25–20 per cent. chromium-nickel steel.

The importance of using the 25–20 and not the 18–8 type of chromium-nickel stainless steel is urged, since the latter type is not satisfactory from a magnetic point of view. Typical errors which could be introduced through magnetic effects liable to occur with weights of the 18–8 composition are quoted.

For less expensive sets of good quality the National Physical Laboratory recommends brass weights plated with rhodium, platinum, or chromium, over a suitable underplating, or with a tin-nickel alloy (65–35 per cent.), provided that the total thickness of the plating is at least 0·015 mm. Recommendations for maintenance of all types of weight are made.

With regard to stability of the respective types, under laboratory and other working conditions, it is recorded that weights of non-magnetic 80–20 nickel-chromium alloy and 25–20 chromium-nickel stainless steel have proved highly stable in use at the National Physical Laboratory under good conditions, and some account is given of results reported for weights of various types in use in chemical laboratories in which corrosive atmospheres were prevalent. Here, again, the record of the nickel-chromium-alloy and stainless-steel weights was satisfactory, and weights plated with chromium or tin-nickel alloy also gave good resistance to deterioration.

Catalysts for Hydrogenation

See abstract on p. 207.

NICKEL

Nickel Catalysts

W. M. KEELY: 'Hydrogenation and Hydrogenolysis.' *Industrial and Engineering Chemistry*, 1954, vol. 46, Sept., pp. 1846–61.

This article is one of a series contained in the I. and E.C. '7th Annual Review of Current Developments in Chemical Engineering Unit Processes'. It is based on the 1953 literature covering the following aspects of the subject:—

Hydrogenation of carbon monoxide, hydrogenation of acetylene and acetylenic compounds, ammonia synthesis, hydrogenation of petroleum and hydrocarbons, hydrogenation of coal, hydrogenation of various organic compounds, and fundamental studies of hydrogenation catalysts.

Each section is supported by a selected *bibliography*. A considerable amount of information is given on nickel-containing catalysts of various types.

K. HEINLE and K. KROGMANN: 'Catalysis on Sintered Nickel Powders.' *Naturwissenschaften*, 1953, vol. 40, pp. 528–9; *Chemical Abstracts*, 1954, vol. 48, July 25, p. 8143.

Report of experiments made with nickel catalysts prepared by compressing carbonyl-nickel powder into briquettes under 1–20 tons per sq. cm. and sintering under argon at temperatures up to 600°C. or above, for periods varying up to 24 hours. Decomposition of HCO_2H was used as the criterion of the activity of the catalysts. For further details see *Chemical Abstracts*, *loc. cit.*

Substructure, Tensile Strength and Creep Relationships in Nickel and Nickel Alloys

See abstracts on p. 209.

ELECTRODEPOSITION AND OTHER COATING METHODS

Deposition of Nickel from Sulphamate Baths

R. C. BARRETT: 'Nickel Plating from the Sulfamate Bath.' *Plating*, 1954, vol. 41, Sept., pp. 1027-32; disc., p. 1033.

(Full form of paper referred to, from abstract source, in *Nickel Bulletin*, 1954, vol. 27, Nos. 7–8, p. 129.)

The author makes a well-documented review of the development of the sulphamate type of electrolyte. The unique properties of sulphamic acid and its salts are discussed and the advantages of plating solutions based on them are emphasized, from the point of view of the characteristics of the deposit obtained (*see below*), non-toxicity and ease of operation.

The basic solution recommended for a general-purpose sulphamate bath is of the following composition:—

	oz./gal.
Nickel sulphamate	60
Nickel metal content	10·2
Boric acid	4
Anti-pitting agent	0·05

Ranges of operating conditions, when using this bath, are given as:—

Temperature	100°–140°F. (38°–60°C.)
pH (colorimetric) ..	3·0–5·0
Density (Bé)	29–31
Anodes—Nickel 99% plus; rolled, depolarized	
Cathode current density (max.)—	
	300 amp./sq. ft. at 140°F. (60°C.)
	150 amp./sq. ft. at 100°F. (38°C.)
Agitation—Cathode bar movement or solution circulation	
Tank voltage	6–9
Anode efficiency	100%
Cathode efficiency	98–100%

The average properties of the deposits made from the basic solution operated within the above limits are quoted as:—

Hardness	250–350 Vickers
Elongation, in 2 in.	20–30 per cent.
Tensile Strength	90,000 p.s.i.
	40·2 t.s.i.
Internal stress (tensile) ..	500 p.s.i.
Colour and appearance of deposit—	White; semi-matte to lustrous.

By means of slight modifications in composition of the solution and/or operating conditions, plus the use of recommended addition agents, deposits giving a wide range of properties can be secured, e.g., hardness may be increased to 550 Vickers, stress can be controlled and made compressive, tensile strength can be raised, a semi-bright to fully-bright appearance can be produced, and high levelling characteristics can be ensured.

The advantages of the sulphamate type of solution are considered, under the following headings:—

- Ability to produce deposits free from internal tensile stress, or even containing compressive stress.
- Operation at high current densities, at relatively low temperatures.
- Simplicity of composition; ease of control and maintenance.
- Low sensitivity to impurities.
- Production of nickel deposits of high chemical purity.
- Wide latitude of operating conditions.
- Wide range of properties producible.
- Improvement in fatigue strength of the basis metal on which such deposits are made.
- Fine grain structure and good ductility of the deposits.
- High levelling action, resulting in ease of buffing.

In connexion with plating equipment it is noted that sulphamate solutions can be used in any plant normally used for handling high-chloride Watts-nickel solutions, provided that lead be excluded from contact with the electrolyte.

The author discusses at some length the degree of internal stress present in deposits made from various types of nickel plating bath. As a result of extensive investigation of electrodeposits made from the sulphamate bath under varying conditions of solution and operation, the following summary is given of

the effects of all variables on the stress present in the deposits:—

pH	Stress shows slight minimum at pH 4·0. Increases slowly at lower pH values, and sharply at values above 6·0.
Metal content	No appreciable influence on stress.
Temperature ..	Stress decreases with rise in temperature of bath, and increases with drop in temperature, usually by not more than a total of ±5,000 p.s.i. for the extremes.
Chlorides ..	Stress rises sharply and linearly with increasing chloride content: approximately 3,000 p.s.i. for each 10 per cent. increase in chloride as nickel chloride.
Current density	Stress increases gradually with rise in current density.
Agitation ..	Agitation reduces the rate of increase of stress with rise in current density.
Boric acid ..	No appreciable effect on stress, within the range of 2·0–5·0 oz./gal.
Wetting agent	Acts slightly as stress reducer.

The advantages of the sulphamate bath in permitting high current density at low operating temperatures is emphasized in relation to electroforming and electrotyping applications, and the usefulness of coatings having compressive stress is urged in relation to the needs of the aircraft industry, in which the effect of plating on the properties of the basis material is of primary importance.

Bright Nickel as Undercoat for Chromium-Plated Bumpers

R. D. MILLER: 'Bright Nickel Process Simplifies Bumper Manufacture.' *Products Finishing*, 1954, vol. 18, June, pp. 24–30.

The article describes the cycle of operations which has been standardized by Electric Auto-Lite Company, U.S.A., for plating of automobile bumpers. After preparatory treatment, details of which are given, the parts are subjected to the following treatment:—anodic cleaning; hot-water rinsing; anodic etching in 50–55°Bé. sulphuric acid; cold-water spray rinsing; striking in Watts nickel bath; spray rinsing; nickel plating in a Harshaw Perflow solution (in which the major portion of the nickel coating is deposited); plating in Harshaw bright-nickel Perglow solution; final water rinsing. The plated parts are then 'colour wiped' on automatic buffing machines specially designed for the operation, and placed in a standard chromic-acid solution for finishing.

Tin-Nickel Alloy Plating

'Tin-Nickel Alloy Plating.' *Automobile Engineer*, 1954, vol. 44, Aug., pp. 320–2.

The article draws attention to the usefulness of tin-nickel alloy plating as a decorative and protective coating. Particulars are given of the composition of the electrolyte, the plating equipment required, selection and treatment of the tin and the nickel anodes, operating conditions, and maintenance of the solution.

Notes are added on the corrosion-resisting properties of the alloy coatings, and their physical characteristics. Patent rights for the process are held by the Tin Research Institute, but licences to use it are granted without fee.

Effects of Nickel-Dip Treatment in Enamelling of Steel

J. C. RICHMOND, H. B. KIRKPATRICK and W. N. HARRISON: 'A Radioisotope Study of the Nickel Dip.' *International Enamelist*, 1954, vol. 4, No. 2, pp. 14–15. Abstract of paper presented to American Ceramic Society.

The authors report results of experiments carried out, at the National Bureau of Standards, to study:—

(1) the effect of surface pre-treatment on the amount of metallic cobalt deposited at the enamel metal interface during firing of a cobalt-bearing ground coat on iron, using a radioactive cobalt-bearing ground coat.

(2) the effect of surface pre-treatment of enamelling iron on the amount and distribution of nickel deposited from the nickel dip, using a radioactive nickel-dip solution, and

(3) the physical location and chemical form of the nickel deposited from the nickel dip on iron after application and firing of cobalt-bearing and cobalt-free enamels, using specimens which had been treated in radioactive solution.

The use of radioactive nickel in the nickel dip was found to offer many advantages for studying the deposition of nickel by this process. Autoradiographs gave a true picture of the actual distribution of the deposits, with good resolution: radio assays gave a quick, non-destructive method of determining the amount of nickel deposited, and repeated radio assays could be made on the same area of a specimen to evaluate the effect of various treatments on the amount of nickel retained by the iron.

The results of the experiments are summarized as follows:—

(1) Nickel from the nickel dip had little or no effect on the deposition of cobalt metal during firing of a cobalt-bearing enamel on iron.

(2) Surface preparation markedly affected the deposition of cobalt metal during firing of a cobalt-bearing ground coat on iron. Heavier deposits occurred on sandblasted than on pickled iron.

(3) The nickel deposited from the nickel dip was always non-uniform, but the scale of non-uniformity was markedly affected by the prior treatment of the metal.

(4) Heavy deposits of nickel from the nickel dip occurred at areas which had previously been subjected to severe cold work.

(5) The amount of nickel deposited in the nickel-dip treatment of enamelling iron was markedly affected by the prior treatment of the steel. Heaviest deposits occurred on sand-blasted iron, next heaviest on polished iron, and lightest on pickled iron. Pickling after sandblasting or polishing prior to the nickel-dip treatment reduced the amount of the deposit, as did excess time in the rinse water following pickling.

(6) The nickel from the nickel dip remained as metal at the enamel/metal interface during firing of both cobalt-bearing and cobalt-free enamels on nickel-dipped iron. There was no evidence of oxidation of the nickel followed by solution into

the enamel glass, but there was some evidence that part of the nickel may have been separated from the metal by undercutting, particularly on continued firing.

Nickel-Chromium-Plated Weights

See abstract on p. 206.

NON-FERROUS ALLOYS

Substructure and Tensile-Strength Relationships in Nickel and Nickel Alloys

B. ANCKER and E. R. PARKER: 'Quantitative Substructure and Tensile-Property Investigations of Nickel Alloys.' *Jnl. of Metals*, 1954, vol. 6, Oct.; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 1155-62.

The mechanism of deformation of metals is at present incompletely understood. Single crystals and individual grains in polycrystalline aggregates often develop a sub-grain structure when deformed: substructure formation occurs as a result of local plastic bending, and its development is intensified by annealing at moderate temperatures. Investigations carried out to date, which have been mainly qualitative in character, have shown that the substructure is composed of a network of small-angle boundaries. The present contribution to the subject presents quantitative data on substructure (obtained by X-ray techniques), and correlates the results with the strength of the metal.

The work described was carried out on specimens of high-purity nickel, two nickel-titanium alloys (1 and 2 at.- per cent. titanium) and two nickel-cobalt alloys (5 and 20 at.-per cent. cobalt). Tensile specimens having a reduced section, $\frac{1}{4}$-in. diameter by 3-in. long, were machined from the alloys, which had been refined, cast, forged and swaged in the laboratory. The specimens were annealed for $\frac{1}{2}$ hour at 1150°C., a treatment which produced grains having a diameter of approximately 0·5 mm. (This somewhat large grain size was used to facilitate subsequent examination of the substructure.) Duplicate specimens of the nickel and of each alloy were strained to various controlled amounts in tension at room temperature, and given a recovery treatment of one hour at 800°C. (This strain is designated 'pre-strain'.) One each of the 'recovered' specimens was pulled in tension at room temperature, to obtain the stress-strain curves. The other bar was cross-sectioned in the gauge length, polished, and deeply etched, to remove all cold-worked material. These latter specimens were then examined by X-ray microscopic technique, to determine the nature and magnitude of the substructure. Use of duplicate specimens permitted direct correlation of tensile properties with substructure characteristics.

The experimental results, reported at length, show that:—

(1) Increasing amounts of deformation, followed by recovery treatment, caused a regular gain in the strength of all the materials examined. The recovered materials were not so hard as those which had not been so treated, due to the fact that many internal barriers to slip were destroyed during recovery. In contrast to this softening effect, the small-angle boundaries introduced by room-temperature deformation become sharper during recovery and thus much more effective in hardening the metal.

(2) The strength of the annealed alloys increased linearly with increase in alloy content.

(3) Observations on substructure density of the alloys as a function of composition lead to the conclusion that this is not the only factor of significance in establishing the strength of an alloy.

(4) The number of small-angle boundaries developed by room-temperature deformation is substantially unchanged by heating at temperatures up to 800°C. The nature of the network is, however, dependent on the temperature of the recovery treatment; the higher this temperature the sharper will be the sub-boundaries.

(5) Dislocation density may increase without a corresponding increase in substructure density: this was found to be the case for the nickel-cobalt alloys.

(6) It is considered that two different types of hardening may be operative, respectively, in the nickel-cobalt and the nickel-titanium alloys.

See also closely related paper of which abstract is given below.

Influence of Substructure on Creep Properties of Nickel and Nickel Alloys

T. H. HAZLETT and R. D. HANSEN: 'Influence of Substructure on the Shape of the Creep Curve.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 20; 10 pp.

The work reported in this paper was done in the same laboratory as the tests recorded in the preceding abstract.

The data obtained had led to the conclusion that the tensile strength of a given material depends to a great extent on the sub-structure state and that the larger the amount of substructure the greater is the strength. This conclusion was supported by the finding that flow stress increases as the amount of stable substructure increases. The work now reported was designed to determine the influence of the state of the substructure on the creep properties of pure nickel and of solid-solution nickel-base alloys containing $\frac{1}{2}$ at.-per cent. of titanium, *or* 5 at.-per cent. of iron, *or* $2\frac{1}{2}$ or 20 at.-per cent. of cobalt.

A series of curves shows the effects of controlled amounts of pre-strain and recovery, on the creep properties of the respective materials. The results obtained demonstrate that the shape of the creep curve for a given material may be drastically changed, from continuously decreasing to continuously increasing rate of creep, by first subjecting the specimens to a pre-strain and recovery treatment which induces a stable substructure in the material. The creep-resistance of pure nickel and of the solid-solution

nickel alloys tested is markedly increased by such treatment. The amount of substructure present at the beginning of a creep test is not, however, the only factor determining the shape of the creep curve.

Sigma Phase: Review

See abstract on p. 217.

Jet-Impingement Testing of Condenser-Tube Alloys

See abstract on p. 219.

Welding of Monel and K Monel

F. A. BALL: 'The Welding of Monel and K Monel.' *Reprint from Sheet Metal Industries*, July and Aug., 1954; 12 pp.
Henry Wiggin & Co., Ltd. *Publn.* 771.*

This paper, presented at a symposium on 'The Non-Ferrous Metal Industry in India' in February of this year, gives a detailed and well illustrated account of welding technique suitable for use with the nickel-copper alloy and its aluminium-containing modification. Defects likely to occur due to incorrect operating conditions are reviewed, with illustrations of typical cases, and recommendations are made for means of avoidance.

NICKEL-IRON ALLOYS

Structural Investigation of Alnico Permanent-Magnet Alloys

K. J. KRONENBERG: 'Magnetically Oriented Structure in Permanent Magnets.' *Zeitsch. f. Metallkunde*, 1954, vol. 45, July, pp. 440–7.

With a view to further elucidation of some of the questions which are still in debate with regard to the structure of polycrystalline permanent-magnet alloys of the nickel-aluminium-iron-base types, the author made a detailed study of an alloy containing iron 51, cobalt 24, nickel 14, aluminium 8, copper 3, per cent. Oxide replicas were examined, by the electron microscope, of the alloy in the condition produced by cooling in a magnetic field over the range 950°–750°C. and after re-heating at 800°C. A coarse heterogeneous structure observed after the re-heating treatment is illustrated and discussed. Observations relating to the structure/magnetic property relations made are essentially in agreement with results reported by HEIDENREICH and NESBITT, who worked on single-crystal material (*Jnl. Applied Physics*, 1952, vol. 23, pp. 352-65; 366-71). In addition, the present author found, on examining very thin replicas, a highly disperse oriented microstructure, the nature and dispersion of which confirm assumptions which have been made with regard to the presence of a magnetically-operative structural heterogeneity. Full details of technique of examination are given, and the paper is illustrated by more than 40 electron micrographs.

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CAST IRON

Ni-Hard Abrasion-Resisting Cast Iron

MOND NICKEL CO., LTD.: 'Ni-Hard: Nickel Cast Iron. A Summary of Properties and Applications.' *Publn.* 736*, 1954; 16 pp.

Ni-Hard is a white cast iron alloyed with nickel and chromium to produce a material having high hardness and outstanding resistance to abrasion. Service for twenty-five years in the cement, mining, coal, metallurgical and other industries has proved the economic value of Ni-Hard for components such as grinding balls, mill liners, pulverizing machinery, slurry pumps, rolls, piping, etc. This type of iron is made in many foundries, in all parts of the world, under various trade names, e.g., Diamite, ABK metal, Elverite C, Michalloy, Nichillite, Adamite.

The publication contains details of composition of two grades of Ni-Hard, one for applications in which high hardness is a primary requisite, the other for use when particularly high tensile strength is called for. Physical and mechanical properties of both grades are tabulated, structures typical of the iron (in the sand-cast and the chill-cast conditions) are illustrated, and their general characteristics are described, with reference to applications in which the respective properties are utilized. A table shows some comparisons of service life of castings of (*a*) Ni-Hard, and (*b*) white iron, in components used in industries in which abrasion-resisting materials are essential to successful working.

Nickel-Alloy Cast Iron in Marine Components

E. C. PIGOTT: 'Marine High-Duty Cast Iron Replaces Steel.' *Iron and Steel*, 1954, vol. 27, Oct., pp. 441–5.

The author reports the successful use, for valves and other steam-line components, of a cast iron containing total carbon 3·1–3·2, silicon 1·6–1·8, manganese 0·9–1·1, sulphur 0·07 max., phosphorus 0·1–0·2, nickel 1·7–1·9, chromium 0·6–0·7, copper 0·8–0·9, molybdenum 0·25–0·30, per cent. Castings of this composition meet the requirements of B.S. 1452:1948, Grade 20, and have given consistently satisfactory service in vessels operating in various conditions, in all parts of the world.

Oxidation-Resistance of Cast Irons

J. A. CAMERON: 'Oxidation of Plain, Alloyed and Ductile Irons at 1300°F.' *Corrosion*, 1954, vol. 10, Sept., pp. 295–7; disc., pp. 297–8.

Oxidation tests up to 4,000 hours in duration, at 1300°F. (705°C.) were made on typical specimens of grey cast iron, unalloyed spheroidal-graphite cast iron, high-silicon spheroidal-graphite cast iron, standard Ni-Resist Type 2 (nickel 20, chromium 2 per cent. approx.), S.G. Ni-Resist Type 2 and a high-silicon grade, carbon steel, and a straight high-chromium stainless steel. Exposure was in a Leeds and Northrup Homo tempering furnace equipped with a fan for circulation of air. The tests were intermittent, the

average individual exposure periods being of about 150 hours' duration. Results are shown in terms of (*a*) actual oxide penetration, and (*b*) inches per year.

The following conclusions are drawn from the results obtained:—

'The oxidation-resistance of S.G. irons is markedly superior to that of ordinary grey cast iron containing flake graphite. Part of this increase may be attributable to increased silicon and nickel contents, but most of it must be due to the difference in graphite structure. The oxidation of ordinary cast iron containing flake graphite may be visualized as progressing inward from the surface more or less uniformly until the metal-oxide interface reaches graphite flake. This graphite flake is then oxidized entirely in a short time and newly exposed metal surface is then exposed to attack. Such an effect should be reduced in the case of S.G. iron because the spheroidal graphite has a lower surface-to-volume ratio than flake graphite. Furthermore, the distance between graphite particles is greater for S.G. iron. This increases the distance through which oxygen must diffuse before internal oxidation can take place, and therefore reduces the rate of such oxidation.

'At 1300°F. (705°C.) S.G. Ni-Resist Type 2 is slightly more resistant to oxidation than the same iron of flake-graphite structure, but the difference is considerably less than that between S.G. and flake-graphite grey cast irons. Work by other investigators, still in progress and therefore unpublished, indicates that at temperatures in the range 1700°-1750°F. (925°-955°C.) the difference between the two grades of Ni-Resist is much greater than that found at 1300°F. (705°C.), which is apparently too low a temperature correctly to differentiate between the two.

(*See also discussion by* MILLIS, *below.*)

'Increasing the silicon content of S.G. iron and of S.G. Ni-Resist increases resistance to oxidation at 1300°F. (705°C.), but the higher-silicon irons are very sensitive to shock, either mechanical or thermal. Ductility of high-silicon irons is low even when the graphite is spheroidal.

'Spheroidal-graphite iron of normal composition showed, at 1300°F. (705°C.) oxidation-resistance about equal to that of regular or S.G. Type 2 Ni-Resist. In some cases, therefore, the unalloyed S.G. iron could be used as an alternative to the Ni-Resist, but in other types of service, where the high-temperature strength or coefficient of thermal expansion characteristic of Ni-Resist is essential, such interchange would not be feasible.

'The oxidation-resistance of high-silicon S.G. Ni-Resist and of S.G. iron of high silicon but otherwise normal content, is about equal to that of the straight high-chromium steel; all three materials were almost completely resistant within the limits of these tests.

'At 1300°F. (705°C.) both the ordinary grey cast irons were superior to low-carbon cast or wrought steel, but neither exhibited a degree of resistance which would be satisfactory in any important application.

'Rate of oxidation decreased with time and it is to be presumed that extension of the tests to 8,000 hours would have resulted in rates appreciably lower than those contained in this report.'

In assessing the relative behaviour of the respective materials, the authors express the opinion that although correlation of laboratory tests with service conditions is at best approximate, the resistance of the materials to deterioration in an environment composed principally of air and oxidizing gases would be likely to be similar to that shown in the laboratory exposures. Relatively large proportions of other gases, such as hydrogen sulphide or acid vapours, might reverse the position of some of the materials. No examination was made, in these experiments, of the mechanical strength of the steels and irons at the test temperature.

In discussion, K. D. MILLIS presented data confirming the superior resistance to oxidation characteristic of cast irons in which the graphite is present in spheroidal form. In the series of tests to which he made reference temperatures up to 1750°F. (955°C.) were involved, and exposure was in a heat-treatment furnace. The furnace was operated cyclically, each cycle consisting of a four-hour heating to 1750°F. (955°C.), holding at that temperature for seven hours, and cooling to 600°-700°F. (315°-370°C.) before starting the next cycle. Each cycle occupied 24 hours and once a week the furnace was cooled to room temperature. One rack of specimens was exposed for 45 cycles, the other for 100 cycles. The results are tabulated in the original.

This work confirms the increased oxidation-resistance conferred by high silicon content in S.G. iron, but Millis emphasized the importance of careful consideration of the embrittling influence of silicon. Attention was directed to the fact that the oxide scale formed on S.G. iron is of a more protective nature than that formed on steel and malleable iron.

CONSTRUCTIONAL STEELS

Ultra-High-Strength Steels for Aircraft

SOC. AUTOMOTIVE ENGINEERS: 'Symposium on Ultra-High-Strength Steels in Aircraft Applications.' *Publication S.P.* 120*, 1954; 73 pp.

Reprint of papers presented at symposium held in March, 1953.

For abstracts of contents see *Nickel Bulletin*, 1954, vol. 27, No. 10, pp. 193-5.

Effect of Composition on the Properties of Slack-Quenched Steels

J. VAJDA and P. E. BUSBY: 'Effect of Composition on Transverse Properties of Slack-Quenched Steel.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 24; 15 pp.

The information presented in this paper is supplementary to that contained in an earlier publication,

* *We shall be pleased to supply a free copy of this publication.*

which gives a detailed account of an end-quench method for developing reproducible slack-quenched structures in heavy forgings and of the properties of some steels evaluated by that method (see *Trans. Amer. Soc. Metals*, 1954, vol. 46, p. 1331). This second paper records results more recently obtained, on ten additional steels, showing the effects of boron, rare-earth oxides, silicon, nickel, and carbon, on transverse properties. The end-quench method is discussed in relation to its applicability to heavy sections, and some data on the effect of mass on properties are presented.

The results, which broadly confirmed, and amplified, the conclusions drawn from the earlier experiments, showed that:—Grainal No. 79, a material rich in both boron and titanium, was more effective than ferroboron in improving hardenability. Additions of boron, carbon, silicon and nickel improved hardenability, as measured by 1-in. and 7-in. end-quenched bars, but rare-earth oxides added to a steel treated with ferroboron had no significant influence on hardenability.

Boron lowered the transverse impact strength of slack-quenched steels; the intensity of the effect varied according to the form of the boron addition. Rare-earth oxide additions to a boron-treated steel had a slightly deleterious effect on transverse reduction of area and transverse impact strength.

At certain rates of cooling silicon improved impact quality, as a result of increased hardenability, but at sufficiently slow rates of cooling it had the reverse effect. Nickel additions improved impact strength without affecting tensile properties.

In a steel of higher carbon content (0·15 per cent.) yield strength and transverse ductility were, on the average, lower, and the toughness was higher, than in 0·30 per cent. carbon steels of comparable composition.

Experimental evidence on the effect of mass on mechanical properties was inconclusive, but the results suggest that there may be slight lowering of transverse impact quality, and possibly also of yield strength, with increase in mass.

Effects of Carbon and Nitrogen in Nickel-Alloy and Other Steels

A. E. NEHRENBERG, P. PAYSON and P. LILLYS: 'Effect of Carbon and Nitrogen on the Attainable Hardness of Martensitic Steels.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 16; 12 pp.

It has been frequently observed that the hardness attainable in low-carbon high-alloy steels (such as the martensitic stainless steels) is somewhat greater than would be predicted from the relation between carbon content and maximum hardness of martensite developed by BURNS, MOORE and ARCHER (*Trans. Amer. Soc. Metals*, 1938, vol. 26, p. 1). Possible reasons for this discrepancy are discussed by the present authors, who demonstrate that the maximum hardness is a function of nitrogen as well as of carbon content. The conclusions are based on observations made on 54 experimental steels, some prepared specifically for this investigation, others representing types which had been used for various other projects. The carbon contents varied from 0·035–0·16 per cent., chromium from about 0·5 to about 15·5 per cent., and in the steels of relatively low chromium content additions of nickel, up to 6 per cent. and of manganese up to 3 per cent., were made. The steels containing 12–15·5 per cent. chromium contained only residual nickel and molybdenum, together with normal amounts of silicon and up to 2 per cent. of manganese. Nitrogen content was varied from about 0·030 to about 0·30 in the higher-chromium steels, but in the lower-chromium types it was present in smaller percentages. Full analyses of all the steels are given in the original.

The results indicate that the maximum hardness which can be attained in steels heat-treated to have fully martensitic structures free from residual carbides may be regarded as a logarithmic function of the carbon and nitrogen contents. Variation in chromium from 0·5 to 15·5 per cent. in steels containing 0·035–0·16 per cent. of carbon appeared to have no significant effect on the hardness attainable.

In martensitic chromium stainless steels containing 0·10 per cent. of carbon an increase in nitrogen content from 0·01 to 0·05 per cent. increases attainable hardness by 5·5 points Rockwell C. The following equation is proposed to describe an empirical logarithmic relationship between attainable hardness and carbon and nitrogen contents:—

$$\log \text{Rockwell C hardness} = 2{\cdot}182 + 0{\cdot}469(\log C) + 0{\cdot}108(\log C)^2 + 0{\cdot}164(\log N) + 0{\cdot}025(\log N)^2.$$

where C = carbon content, wt. %.
N = nitrogen content, wt. %.

Magnetic Method for Determination of Continuous-Cooling Diagrams in Nickel-Alloy Steels

R. D. CHAPMAN and W. E. JOMINY: 'A Method for Determining the Continuous-Cooling Transformations in Steel.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 33; 16 pp.

The authors describe equipment and technique, and report results obtained on four commercial alloy steels, including three of low and medium nickel content. The equipment used in this magnetic method is an electrical transformer in which the specimen acts as a core. As transformation takes place in the steel the permeability is increased, producing an e.m.f. in the secondary winding of the transformer. On the steels studied, good agreement was found between metallographic and magnetic determinations of M_s. The equipment was used also to develop continuous-cooling diagrams for a nickel-chromium-molybdenum (S.A.E. 4340) and a low-manganese (S.A.E. 4063) steel. These tests indicated that better definition of the bainite areas is obtained by the magnetic method than by metallographic technique.

Precision Investment Casting of Nickel-containing Materials

See abstract on p. 206.

Inter-Relation of Structure and Hardenability in Steels

S. T. ROSS, R. P. SERNKA and W. E. JOMINY: 'An Electron Metallographic Study of the Dependence of Microstructure on Hardenability.'
Trans. Amer. Soc. Metals, 1954, vol. 47, Preprint 13; 18 pp.

The purpose of the investigation described was twofold: (*a*) indentification, and (*b*) prediction of the nature, of transformation products associated with martensite in incompletely hardened steels. Six commonly used hypoeutectoid steels in the 0·40 per cent. carbon range were selected for study: three were shallow-hardening, the others relatively deep-hardening types. Compositions are shown in the Table below:

Type	A.S.T.M. Grain Size	C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
S.A.E. 1040	7–8	0·42	0·71	0·017	0·026	0·24	0·08	0·16	0·01
S.A.E. 1340	8–9	0·41	1·88	0·019	0·024	0·29	0·02	0·04	0·03
S.A.E. 4040	7–8	0·45	0·84	0·011	0·028	0·25	0·03	0·04	0·24
S.A.E. 4340	8–9	0·41	0·70	0·012	0·022	0·26	1·82	0·99	0·21
S.A.E. 5140	7–8	0·42	0·82	0·020	0·030	0·28	0·10	0·86	0·06
S.A.E. 8640	8–9	0·42	0·86	0·024	0·030	0·23	0·50	0·45	0·20

Full details of heat-treatment, experimental technique, and results for each steel are given in the report.

The authors show that transformation products associated with martensite in incompletely hardened steels can be resolved and identified by electron microscopy. In the shallow-hardening steels (S.A.E. 1040, 1340 and 4040) these products consisted of ferrite and ferrite-carbide agglomerates identified as pearlite and upper bainite. In the deeper-hardening steels (S.A.E. 4340, 5140 and 8640) the transformation products were ferrite and ferrite-carbide agglomerates identified as upper and lower bainite.

It is found that the nature of the transformation products in incompletely hardened alloy steels can be predicted from consideration of applicable hardenability data and cooling transformation diagrams.

With each individual steel investigated the same transformation products were always present, whether the steel contained 90, 70 or 50 per cent. of martensite. The physical appearance of the ferrite and carbide phases comprising the constituents of the transformation products is the same for all the steels studied.

On the basis of magnetic and electron-microscopic evidence, the extent of the pro-eutectoid ferrite area generally accepted for the S.A.E. 4340 steel cooling transformation diagram is considered to be questionable, and the authors are of the opinion that isothermal data on other steels also require further investigation, by the methods used in this research.

Calculation of Hardenability: Influence of Nickel and Other Elements

C. F. JATCZAK and R. W. DEVINE: 'Calculations of Hardenability in High-Carbon Alloy Steels.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 14; 21 pp.

The paper is based on information accumulated over a long period, in works producing case-hardened bearing races. The approach to the problems involved has been essentially practical and the data now published comprise a systematic correlation of individual observations and measurements, in a form permitting study of the influence of the respective elements present in the steels used.

For the materials subjected to end-quench hardenability tests a standard nominal carbon content of 1 per cent. was maintained, as representing the maximum carbon content of the surface of the carburized races. Standard A.S.T.M. end-quenching procedure was used throughout, except that final austenitizing treatment was in a neutral salt bath. Duplicate specimens were subjected to a 45-minute austenitizing treatment at each of three temperatures, 1475°, 1525° and 1575°F. (800°, 830° and 855°C.). The criterion of hardenability used was the distance to Rockwell C-60, a value close to that acceptable as a minimum for bearing components and for most tool-steel applications.

The types of steel examined were as follows:—

Single-Alloy Steels

Manganese	0·32–1·14 per cent.
Nickel	0·34–2·04 „ „
Chromium	0·53–2·10 „ „
Molybdenum	0·12–0·43 „ „
Silicon	0·26–0·66 „ „

Multi- Alloy Steels

Nickel–chromium–molybdenum types containing varying nickel or molybdenum.

'Lean–alloy' nickel–chromium–molybdenum steels containing varying silicon.

High–manganese chromium–molybdenum steels with low nickel.

The authors propose an empirical procedure, based on multiplying factors, for calculation of hardenability. For the steels under consideration this method was found to predict hardenability within about ±10 per cent. for normalized steels and ±15 per cent.

for annealed steels. Full details of procedure are given, together with supporting curves relating to the individual types of steel examined.

Tensile and Impact Properties of Low-Carbon Martensitic Steels

C. C. BUSBY, M. F. HAWKES and H. W. PAXTON: 'Tensile and Impact Properties of Low-Carbon Martensites.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 9; 22 pp.

The purpose of the investigation reported was to obtain new basic information about low-carbon martensitic steels, in order to further development of high-strength steels showing improved ductility and toughness at various levels of tensile strength.

The mechanical properties of 38 martensitic steels (carbon 0·11–0·28 per cent.) were determined, in the as-quenched, and the quenched-and-tempered conditions. The compositions of the steels were representative of low-alloy nickel-chromium-molybdenum types with or without about 0·1 per cent. of vanadium, chromium-manganese and nickel-chromium grades, an S.A.E. standard 2320 nickel steel (nickel 3·25–3·75 per cent.), and a 4615 nickel-molybdenum type (1·65–2·00/0·15–0·25 per cent.) All the steels were fine-grained and aluminium-killed.

From the test results the following conclusions are drawn:—

(1) In the brine-quenched condition low-carbon steels containing 0·16–0·28 per cent. carbon had essentially no ductility, as measured by the tensile test, but those containing 0·15 per cent. or less of carbon showed appreciable ductility.

(2) Tempering at 100°C. (212°F.) improved all the tensile properties, raising the ductility to values considerably higher than those reported for 0·30–0·50 per cent. carbon steels quenched and tempered to comparable tensile strengths. The yield strength/tensile strength ratio was, however, low (about 0·70).

(3) Within the ranges studied, the amount or type of the alloying element added had no effect on the tensile properties, and refrigeration in liquid nitrogen prior to tempering also had no influence on these properties.

(4) Oil-quenched steels containing 0·18 per cent. or more of carbon had essentially no ductility in the as-quenched condition, but those containing less carbon, when oil-quenched, showed appreciable ductility. Tempering at 100°C. (212°F.) after oil-quenching improved all the tensile properties, although slightly higher ductilities and yield/tensile ratios at the higher tensile strengths were developed by brine-quenching.

(5) In quenched-and-tempered steels containing 0·15–0·28 per cent. of carbon, variation in diameter of test specimen, up to 0·505 in., did not affect the tensile properties (with the exception of yield strength). Yield strength fell with increasing diameter of specimen.

(6) Most of the steels, in both conditions, developed room-temperature impact strengths which were higher than those of 0·30–0·50 per cent. carbon steels quenched-and-tempered to comparable hardnesses. Tempering at 100°C. slightly raised the impact strength and lowered the transition temperature.

(7) Increasing carbon tended to raise the transition temperature. Nickel was most beneficial in lowering it and chromium up to 2 per cent. had a similar but less potent effect. Manganese (0·8–1·5 per cent.) raised the transition temperature, and to that extent damaged impact quality.

(8) All the steels tested showed strain-ageing effects, in both the as-quenched and the quenched-and-tempered conditions: the intensity of the effect increased with increasing deformation and rise of ageing temperature. The few data available from this investigation suggest that strain-ageing lowers impact strength and very slightly raises transition temperature.

Machining of Ultra-High-Tensile Nickel-Chromium-Molybdenum Steel

F. M. RAYBURN: 'Machining of High-Tensile-Strength Steel.' *Reprint from Mechanical Engineering*, Oct., 1953, 4 pp.

Issued by International Nickel Co., Inc., 1954.

The paper describes routine procedure used by Menasco Manufacturing Company, Burbank, California, in machining the S.A.E. 4340 type* of steel, heat-treated to 200,000–220,000 p.s.i. (90–98 tons per sq. in.) tensile strength. The Company is engaged exclusively in the production of aircraft landing gear, which has been in large-scale production at this plant for the past twelve years. Since 1948, nickel-chromium-molybdenum steel of the type mentioned, in the ultra-high-tensile condition, has been standard for this work. Reference is also made to experience gained in machining of the same type of steel in an even higher tensile range (260,000–280,000 p.s.i.; 116–125 tons per sq. in.), and of titanium.

Annealing for Promotion of Machinability in Nickel-Alloy Case-Hardening Steel

H. C. THOMAS: 'Annealing for Optimum Machinability.' *Metal Treatment and Drop Forging*, 1954, vol. 21, Sept., pp. 403–6.

The steel which is the subject of this article is based on the American type S.A.E. 4620, the British equivalent of which is En 34. A typical analysis of such a steel, which is widely used in the tapered roller-bearing industry, is as follows:—carbon 0·20, silicon 0·18, manganese 0·55, sulphur 0·018, phosphorus 0·018, nickel 1·75, chromium 0·28, molybdenum 0·20, per cent. For rapid and economic machining of steel of this and other low-alloy carburizing types, it is desirable to have a structural condition which ensures ready chip breakage and avoidance of excessive tool wear. This article describes annealing treatment developed to produce 'blocky structure', which is described as being of coarse grain (A.S.T.M. 3–4) with micro-constituents consisting of separate

* Carbon 0·38–0·43, nickel 1·65–2·00, chromium 0·70–0·90, molybdenum 0·20–0·30, per cent.

grains of ferrite and of carbide-bearing grains containing little or no ferrite. It is essential that the carbide grains should not contain martensite, since this leads to excessive tool wear.

In steels in which the grain size has been refined during fabrication it has been found necessary to re-heat to 1000°C. and soak at that temperature for two hours in order to produce the required grain size. Cooling must be carried out at controlled rates in order to prevent formation of acicular structure and ensure the 'blocky' structure. Graphs relating rate of cooling and structure are shown in the original article, and recommendations are also made with regard to conditions requisite for prevention of banding in 'blocky' structures. Improvement in machinability of 'blocky-structured' steel, by comparison with that of normalized steel of the same type, is demonstrated.

HEAT- AND CORROSION-RESISTING MATERIALS

Extruded Air-Cooled Gas-Turbine Blading in Nimonic Alloys

'Nimonic Alloy Developments. Extrusion now Possible.' *Engineering*, 1954, vol. 178, Sept. 3, pp. 302–3.

The article gives a summary of information already available on the high-temperature properties of Nimonic 95, the most recently developed member of this nickel-chromium-(cobalt)-base series.

The use of the Nimonic alloys in gas-turbine blading has permitted a continuous rise in the gas temperatures employed, and hence in output and efficiency, but as these temperatures approach those at which forging is carried out the requirement that the alloys should be stiff under operating conditions, yet amenable to hot working, presents a difficult problem.

Provision of cooling systems by the introduction of air passages into the blading has recently been advanced by the application of extrusion to the Nimonic alloys. Not only has the use of this technique simplified the forming of blades having integral cooling passages, but it has also made possible an extension in the range of alloy compositions, to provide materials of improved forging quality.

The Zenith works of Messrs. Henry Wiggin and Company, Limited, the producers of the Nimonic series, has for some time been making aerofoil sections by hot extrusion and subsequent rolling, and work is now sufficiently far advanced to enable a wide range of such forms to be successfully extruded. Typical extruded blades are illustrated in this article, which also includes a diagram demonstrating the effect of air-cooling on the operating temperatures of stator blades, and on heat-distribution. Blades of the designs described are now being made in Nimonic 80A and Nimonic 90, thus providing all the qualities characteristic of these alloys with regard to oxidation-resistance and resistance to thermal shock, while simultaneously making these properties available for service with gas temperatures even higher than those at present employed, an advance which promises still further improvement in overall output and efficiency of gas turbines.

See also—

'Recent Developments of Nimonic Alloys.' *Metal Treatment and Drop Forging*, 1954, vol. 21, Oct., pp. 453–5.

This article also gives some data on the high-temperature properties of Nimonic 95, and makes reference to the development of cooled-blade sections in Nimonic alloys, by extrusion and rolling.

In addition, attention is directed to the suitability of Nimonic DS (nickel 37, chromium 18, silicon 2, per cent., balance iron) for conveyor belts of annealing furnaces. Illustrations of a typical furnace installation incorporating a belt of this alloy are shown.

Emissivities of High-Temperature Materials

S. M. DE CORSO and R. L. COIT: 'Measurement of Total Emissivities of Gas-Turbine Combustor Materials.' *Amer. Soc. Mechanical Engineers, Paper 54-SA-26*; 16 pp.

The authors describe a method of measuring total emissivity, giving a full description of the apparatus used. Emissivity data were obtained, by the technique described, for sheet material of Inconel, Type 310 nickel-chromium stainless steel, nickel-chromium alloy, and mild steel, also for several types of ceramic coatings. All the bare materials were examined in both the as-rolled and the sand-blasted conditions.

The data presented show that combustor-wall temperatures can be reduced by sandblasting of the external surface and application of a suitable ceramic coating on the internal surface. If a black-body flame at 3500°F. (1925°C.) is assumed inside the combustor, ceramic coating of the inside of an Inconel combustor will reduce the radiant heat transfer to the combustor wall by nearly one-third.

Coal-Burning Gas Turbine for Locomotives: Use of Nickel-containing Materials

'Coal-Burning Gas Turbine.' *Engineer*, 1954, vol. 198, Sept. 10, pp. 370–2.

The locomotive Department of Bituminous Coal Research Inc., operating at Dunkirk, New York, has now accumulated over 2,000 hours of operating experience with full-scale, direct-fired coal-burning gas turbines. Approximately half of the test work was conducted on an Allis Chalmers 4250 h.p. gas-turbine power plant designed to fit in the cab-contour limitations of American railway locomotives. This report reviews the performance of the turbine, and describes some changes which have been made in the coal-handling and -preparation gear and in the ash-separation equipment. Inconel and Incoloy nickel-chromium-iron alloys, and nickel-chromium stainless steel have been used in the tubing of the ash-separator plant, and initially S-590 alloy (complex nickel-chromium-cobalt-iron alloy) was selected for the turbine blading. Tests are now being made with

rotor blading of 19–9 DL (an 18–8 type of chromium-nickel steel). The report includes a description of two methods which have recently been devised for study of erosion due to contact with ash.

Effect of Cold Work and Recrystallization on Formation of Sigma Phase

A. J. LENA and W. E. CURRY: 'The Effect of Cold Work and Recrystallization on the Formation of the Sigma Phase in Highly Stable Austenitic Stainless Steels.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 27; 19 pp.

The research described in this paper is part of an overall project planned to investigate sigma formation in many grades of stainless steel. This section of the work covers only highly stable austenitic steels which do not transform to ferrite during cold working: the accelerating influence of ferrite formation on production of sigma phase does not, therefore, come into question.

Two heats of a commercial Type 310 and one heat of a chromium-manganese steel were used: see compositions in Table I.

Table I
Compositions of Steel Examined

Type	C %	Si %	Mn %	Ni %	Cr %	N %
310 (*a*)	0·033	0·44	1·81	20·91	25·26	—
310 (*b*)	0·06	0·48	1·54	19·87	24·90	—
Cr–Mn	0·095	0·54	16·83	1·83	15·12	0·21

Cold-rolled conditions and ageing temperatures are shown in Table II.

Ageing times varied from 1 to 500 hours.

Hardness and bend tests were made on each sample, after which they were sectioned and prepared for metallographic examination. Of the various etchants tried for differentiation of sigma phase from carbides, best results were obtained on Type 310 steels by electrolytic etching with strong hydroxide solutions (as recommended by GILMAN, *ibid.*, 1952, vol. 44, p. 556; see *Nickel Bulletin*, 1951, vol. 24, No. 12, p. 254). For the chromium-manganese steel electrolytic etching in 10 per cent. chromic acid was found to attack the carbides vigorously, leaving the sigma unattacked, but outlined and in relief.

Table II
Cold-Rolled Conditions and Ageing Temperatures

Type of Steel	Cold-Rolled %	Ageing Temperatures °F.	Ageing Temperatures °C.
310 (*a*)	0, 25, 50, 75, 90	1475	800
310 (*b*)	0, 5, 10, 20, 40	1250, 1475, 1600	675, 800, 870
Cr-Mn	0, 10, 25, 50, 75, 90	1200, 1400	648, 760

The amount of sigma present in treated specimens of Type 310 (*b*) steel was estimated by comparison with standard charts. The percentage of sigma was determined by averaging the estimated amount of sigma in at least fifty fields of view, at a magnification of × 500. Start of sigma formation in samples aged at 1250° and 1475°F. (675° and 800°C.) was assessed by X-ray diffraction of extracted residues obtained by electrolysis in a 10 per cent. solution of sodium chloride.

Most of the work was done on steel 310 (*b*), but specimens of all the steels were metallographically examined, and data from Type 310 (*a*) and the chromium-manganese steel were used to substantiate conclusions derived from the more detailed examination of steel 310 (*b*).

The paper contains a detailed report of the experimental findings, which lead to the conclusion that recrystallization is essential for pronounced acceleration of sigma formation in highly stable austenitic steels. The authors consider that the acceleration in such cases is attributable to a recrystallization transformation in which sigma and unstrained austenite of an equilibrium composition are produced by the recrystallization of highly strained austenite of a non-equilibrium composition. If the amount of cold work is less than that required for recrystallization at a given temperature the accelerating effect of cold work is very small, or may even be non-existent. Small degrees of cold work may actually retard formation of sigma, by restraining or preventing the formation of Widmanstätten-type precipitates which form in annealed steels at certain ageing temperatures.

Sigma Phase: Review

A. J. LENA: 'Sigma Phase: a Review.'
'Part II. Effect of Sigma Phase on Properties of Alloys.' *Metal Progress*, 1954, vol. 66, Aug., pp. 94–9.
'Part III. Identification; Theories on Formation of Sigma: Crystal Structure.' *ibid.*, Sept., pp. 122–6, 128.
Concluding instalments of series, of which Part I was abstracted in *Nickel Bulletin*, 1954, vol. 27, No. 9, p. 171.

Part II summarizes information on the influence of sigma phase on mechanical properties (at normal and at elevated temperatures), and on physical characteristics and corrosion-resistance. The effect of sigma on mechanical and physical properties has been shown to be dependent not only on the amount of the phase which is present, but also on its particle size and distribution. In general, sigma increases the notch-sensitivity of all types of stainless steel, and impact strength is a more discriminating indicator of its presence than any other mechanical property. When sigma phase surrounds the grain boundaries ductility at room temperature is much reduced, and resistance to nitric-acid attack is impaired. The influence of sigma on impact-resistance at elevated temperatures is less pronounced, and it is therefore possible in some cases to use sigma-containing steels in heat-resisting applications. Well dispersed sigma may increase the tensile strength of certain types of alloy, but it has not yet been possible to utilize this method of strengthening high-temperature alloys, due to the undesirable effects usually associated with the presence of the phase.

In *Part II* a critical review is made of methods which have been proposed for identification of sigma, with particular reference to difficulties involved in differentiation between sigma and carbides. Details are given of some etching techniques which have, within certain limits, proved successful.

Theories which have been evolved to explain formation of sigma phase are then considered: attention is directed, *inter alia*, to recent observations on the chi phase, which, it is believed, may be an intermediate stage in formation of sigma.

Summarizing the current stage of development, it is concluded that identification of sigma by microscopic methods is reliable provided that an etching reagent and a procedure suitable for a particular steel are used, and that the sigma particles are sufficiently large to be resolved. When the particle size of the constituents is very small X-ray diffraction is often the only positive method of establishing the presence of sigma. The amount of the carbide and sigma phases is, however, frequently too small to be detected by conventional X-ray analysis of bulk material, and it is necessary to concentrate them. Methods which have been successfully used include dissolution of the matrix by electrolysis in 10 per cent. ferric chloride solution or by immersion in a hydrochloric-picric acid solution, after which treatment the residues are cleaned and analyzed by X-ray methods.

The structure of sigma is identical with that of beta-uranium, in that it possesses tetragonal symmetry, but is pseudo-hexagonal along the *c*-axis. The unit cell contains 30 atoms, with lattice parameters of $a=8\cdot79$ kX and $c=4\cdot55$ kX.

The review includes a list of the alloy systems in which sigma phase has been observed.

Oxidation-Resistance of Cast Irons

See abstract on p. 210.

Stainless Irons and Steels: Textbook

J. H. G. MONYPENNY: 'Stainless Iron and Steel. Volume II. Microstructure and Constitution.'
Published by Chapman and Hall, Ltd., London, 1954; 330 pp. Price 55/-.

The author's first volume, covering Stainless Steel in Industry, published in 1926 and later, in revised editions, in 1931 and 1951, has been a standard work in this important field. The second, forming a logical supplement, will be welcomed by both metallurgists and engineers. Although there is indication that the author, at the time of his death, had not yet covered the field of information provided for in his programme, the text (prepared for publication by Professor F. C. THOMPSON) includes reference to most major aspects of structure and constitution.

The book deals essentially with the metallography of the stainless and heat-resisting steels. Consideration is given to the constitutional diagrams of the iron-chromium alloys, both with and without carbon, and to the microstructures of the chromium steels and the influence, on structure, of variations in composition and heat-treatment. The effects of additions of other elements are reviewed in detail, with particular reference to the influence of nickel: the constitutional diagrams of the straight iron-chromium-nickel and the more complex iron-chromium-nickel-base alloy series are discussed at length. Among the phenomena peculiarly characteristic of the respective groups of stainless and heat-resisting materials of chromium-iron and chromium-nickel-iron base, attention is directed to the occurrence of intergranular corrosion in austenitic chromium-nickel and chromium-manganese steels (and methods for its prevention), to the brittleness produced in high-chromium irons by prolonged heating at about 475°C., and to the formation of sigma phase within certain temperature ranges. There is indication that the author had intended to deal, in a final chapter, with the practical significance of the sigma phase, but this section was not written.

Chromium-Nickel-Manganese Steels containing Nitrogen

R. FRANKS, W. O. BINDER and J. THOMPSON: 'Austenitic Chromium – Manganese – Nickel Steels containing Nitrogen.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 29; 31 pp.

The authors outline the history of investigations on the influence of nitrogen in stainless steels, and report extensive experiments made to determine the structure and mechanical properties of a series of steels containing varying percentages of chromium, manganese, nickel, and carbon, with and without nitrogen. A primary object of the investigation was to make

possible practical utilization of the improvement in hot-workability imparted to steels by nitrogen, as a result of its austenite-stabilizing influence.

The limits of composition for the steels tested were placed at chromium 12–18, manganese 1–22, nickel 0–14, carbon 0·05–0·15, per cent., with nitrogen between about 0·12 and 0·18 per cent. Study was made of the phases present in high-nitrogen (0·15 per cent.) steels containing carbon 0·12–0·15, chromium 12, 14, 15, 16, 17, or 18 per cent., with manganese 0–22, nickel 0–14, per cent., after heating for 15 minutes at 1075°C. and air-cooling, and of phases found in chill-cast ingot samples of the same steels at various temperatures. Detailed examination of room-temperature mechanical properties was also carried out, and the influence of composition on impact properties was determined, by room-temperature tests, with and without previous elevated-temperature exposure. The data reported show that the austenitic region is greatly restricted by increase of chromium content, and is expanded by raising the nickel content. Manganese above 15 per cent. tends to enlarge the delta ferrite-austenite region at chromium levels above 15 per cent: this is the maximum chromium content in which a fully austenitic structure can be produced by manganese alone. In steels containing 15 per cent. or more of chromium an increase in austenite stability takes place with rise in manganese content, but, contrary to expectation, the austenite-forming capacity of manganese is weak, since in relatively low-carbon steels of this type it acts primarily as an austenite-stabilizer, rather than as an actual austenite-former.

In steels falling within the range under consideration both nitrogen and carbon generally expand the austenitic region: they are more potent in this respect than nickel. Carbon is somewhat the stronger of the two.

Formation of a fully austenitic structure in the cast condition requires larger amounts of nickel and of nitrogen than are necessary in hot-worked steels: the homogenizing influence of hot work is believed to be responsible for the difference. Since the presence of too much delta ferrite may give rise to difficulties in hot working, composition must be adjusted to ensure a substantially austenitic structure in the cast condition. Steels within the following range are recommended as likely to fulfil these requirements:—chromium 16–17·5, nickel 3·5–4·5, manganese 7–9, carbon 0·06–0·10, nitrogen 0·12–0·18, per cent. It is considered that ingots of such steels should exhibit good hot-working properties if the initial temperature is kept at a maximum of 1225°C.

The steels show satisfactory properties in the hot-worked, solution-treated condition; a solution-treatment temperature of about 1075°C. imparts good ductility and toughness. Work-hardening properties of steels of this type are intermediate between those of 17-7 and 18-9 per cent. chromium-nickel steels. Their welding characteristics are satisfactory and the joints made in them show a good degree of toughness at both room and sub-zero temperatures. The general corrosion-resistance of the modified nitrogen-containing steels, in oxidizing solutions and under atmospheric conditions, is comparable with that of 17-7 chromium-nickel steels, and, as in the case of other austenitic steels, the grades containing not more than 0·08 per cent. of carbon are more resistant to intergranular attack than those of higher carbon content.

Influence of Deformation on Transformations in Austenitic Steels

H. C. FIEDLER, B. L. AVERBACH and M. COHEN: 'The Effect of Deformation on the Martensitic Transformation in Austenitic Stainless Steels.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 30; 19 pp.

Stainless steels of the 18 per cent. chromium, 8 per cent. nickel type are normally austenitic at room temperature, but under appropriate conditions of temperature and strain a portion of the austenite may be transformed to martensite by plastic deformation. A considerable amount of research has already been carried out on the mechanical properties of steels which have undergone such partial transformation: study has been made of the influence of temperature of deformation, composition of the steel, and conditions and temperature of deformation. The results of the main researches are briefly summarized by the present authors, who also review conclusions which have been reached by various investigators with regard to the martensitic transformation during cooling. Their own work was designed to obtain some understanding of (*a*) the martensitic transformation in high-purity materials of the 18–8 chromium-nickel-iron type which transform spontaneously on cooling, and (*b*) the effect of plastic deformation on the transformation in these materials, both during deformation and during subsequent cooling to sub-atmospheric temperatures.

The compositions of the steels used are given in the Table below.

C %	Ni %	Cr %	Mn %	Si %	Mo %	N %	O %
0·127	8·06	19·76	0·003	—	—	0·0004	0·028
0·058	8·48	18·50	—	—	—	0·0002	0·056
0·016	8·42	18·60	—	—	—	0·0001	0·045
0·006	8·33	18·09	—	—	—	0·0011	0·031
0·04	9·1	18·5	0·56	0·59	0·20	0·020	—

Changes in electrical resistance were used as a measure of the inception of martensite formation and its extent: the M_s was determined by a deviation in the linear relationship between resistance and temperature on cooling. Relationship between the amount of martensite formed and the per cent. increase in resistance, as compared with that found in the austenitic state, was determined from room temperature down to −195°C.

The results are presented in three sections, relating, respectively, to transformation occurring in undeformed austenite, transformation during deformation, and effect of plastic strain on subsequent transformation.

The observations made and the conclusions drawn from them are summarized as follows:—

The M_s is highly sensitive to carbon content: each 0·01 per cent. of carbon lowers M_s by approximately 10°C. The M_s of the steels containing 0·127 and 0·04 per cent. carbon is below −195°C.

The lower the carbon content, the greater is the amount of martensite which forms isothermally, and the higher is the initial transformation rate. In each case, however, the isothermal transformation rate is most rapid at −195°C., the lowest temperature for which data were obtained.

The amount of martensite produced by plastic tensile deformation increases as the temperature of deformation is lowered and as the amount of deformation is increased. Small amounts of tensile deformation have a stimulating effect on subsequent transformation during cooling. Maximum stimulation is achieved by elongations of 2-4 per cent.

Mechanical stabilization, or complete suppression of transformation during cooling, can be achieved by producing large elongations by tensile deformation. As the carbon content is lowered increasing degrees of deformation are needed to achieve mechanical stabilization. It is suggested that this inhibiting effect of plastic strain is due to the distorted or sub-grain structure of the deformed austenite, which may interfere with propagation of the martensite.

Effects of Carbon and Nitrogen in Nickel-Alloy and Other Steels

See abstract on p. 212.

Precision Investment Casting of Nickel-containing Materials

See abstract on p. 206.

Anodic Protection of Stainless Steels

C. EDELEANU: 'Corrosion Control by Anodic Protection.' *Metallurgia*, 1954, vol. 50, Sept., pp. 113-16.

In an earlier communication by the author reference was made to the observation that by inducing anodic polarization protection can in some cases be conferred on chromium-nickel stainless steels in solutions which would otherwise be corrosive: see *Nature*, 1954, vol. 173, p. 729; *Nickel Bulletin*, 1954, vol. 27, No. 5, p. 120.

The present article describes experiments which have been carried out to determine the conditions required to confer protection by this means, and gives some results of trials of the method in pilot plant in which 18-8-Mo steel was operating with concentrated sulphuric acid.

The results so far obtained lead to the conclusion that anodic protection is applicable to practical operation, but that simplification of procedure and further confirmation of its efficacy will be necessary before it could be generally adopted. It is also conceded that at present there would not appear to be much call for such a method of protection.

Although most of the work in this connexion has been done on stainless steels, which have a particularly wide range of potentials over which protection is possible, it is believed that the principle might be adaptable to other alloys.

Jet-Impingement Testing of Condenser-Tube Alloys

P. T. GILBERT and F. L. LAQUE: 'Jet-Impingement Tests.' *Jnl. Electrochemical Soc.*, 1954, vol. 101, Sept., pp. 448-55.

Co-operative research on materials for condenser tubes has for some time past been carried on in the U.K. and the U.S.A. Particular attention has been given during recent years to behaviour under the jet-impingement test, which, in the early stages of condenser-tube investigation, was found to simulate the type of attack encountered in sea-water service.

This paper describes the operation of jet-impingement test apparatus in the laboratories of the British Non-Ferrous Metals Research Association in London, and at The International Nickel Company's Marine Corrosion Test Station at Harbor Island, N.C. Differences in results obtained on identical materials in the two laboratories are discussed in relation to variations in test conditions, particular emphasis being laid on the differences observed between results of tests made with water many times recirculated (as in the B.N.F.M.R.A. laboratories) and those obtained with water which is passed through the apparatus only once (as has been regular practice at Harbor Island). The materials used in various series of tests (the results of which are individually reported) included arsenical copper, 70-30 brass, Admiralty brass, aluminium brass, and 70-30, 65-30, 90-10 and 95-5 cupro-nickels containing varying percentages of iron.

The following general conclusions are drawn:—

'Severity of jet-impingement tests with once-through sea water at Harbor Island was much greater than with recirculated sea water, under otherwise similar testing conditions, in the laboratories of the British Non-Ferrous Metals Research Association. Materials that were badly attacked in recirculated water were, however, no more severely attacked in once-through water.

'Tests with once-through water in England gave less severe attack than those with once-through water at Harbor Island, but results otherwise were very similar.

'Under severe impingement-test conditions it was not necessary to have air bubbles in the water for attack to occur. Air bubbles had more effect in recirculated

water in the B.N.F.M.R.A. laboratory than in recirculated water at Harbor Island.

'Relative behaviour of common condenser-tube alloys when tested at the level of severity provided by tests with recirculated water at 15 ft./sec. in the B.N.F.M.R.A. laboratory was in line with their performance under many conditions of practical use.

'Tests at Harbor Island can be made to duplicate results from the B.N.F.M.R.A. laboratory either by reducing jet velocity from 15 ft./sec. to about 4 ft./sec., or by recirculating the water at 15 ft./sec.

'The presence of suspended plankton in the water at Harbor Island is suspected as being the principal factor in increasing the severity of tests with once-through water.

'The greater severity of the test with once-through water at Harbor Island should provide a means for qualifying materials to resist exceptionally severe conditions of impingement attack in practical service.'

Stainless-Steel Coaches for the French Railways

'Multiple-Unit Stock for Paris Suburban Services.' *Railway Gazette*, 1954, vol. 101, Oct. 1, pp. 377–8.

When the Paris–Laroche section of the Paris–Lyons electrification scheme was completed in 1950, improvements in suburban services to and from the Gare de Lyon were effected by operating trains consisting of steam-type passenger stock adapted for push-pull working with electric locomotives. Orders had already been placed for motor coach sets, but these did not begin to be delivered until late in 1953: 54 two-car sets, with trailer, are now on order, and these units are the subject of this article.

The coach bodies are of 18–8 chromium-nickel stainless-steel, fabricated by the Budd shot-welding procedure: the bodywork is self-supporting. The ends of the underframes, incorporating the headstocks and bogie pivot seatings, are of arc-welded and riveted construction, in a high-tensile steel.

The description of the new stock is illustrated by photographs and a dimensional drawing.

Nickel-containing Materials used for Weights

See abstract on p. 206.

Corronel B: Nickel-Molybdenum-Iron Alloy

HENRY WIGGIN AND CO., LTD.: 'The Properties and Applications of Corronel B.' *Publn.* 769, 1954; 8 pp.

The addition of molybdenum to nickel, or to nickel containing small amounts of iron, produces materials which are strongly resistant to corrosion by hydrochloric and phosphoric acids, and, to a lesser extent, by sulphuric acid. Following initial work in U.S.A. and Germany, systematic research was carried out in England on the effect of compositional modification on the corrosion-resistance and mechanical properties of this group of alloys, and in cast form they have been available industrially for some time past. More recently a wrought nickel-molybdenum-iron alloy has been commercially produced under the name of Corronel B.

This publication contains reference information on the physical and mechanical properties of the wrought material, with notes on corrosion-resisting characteristics, and instructions for working, annealing and welding. A brief survey is made of some of the applications for which the nickel-molybdenum-base alloys have proved suitable in the chemical, petroleum, and other industries.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*

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